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The Aesthetics of Low Drag Vehicles

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Geoff Le Good
G L Aerodynamics & Coventry University

Chris Johnson and Brian Clough
Coventry University

Rob Lewis
TotalSim Ltd

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ABSTRACT

Investigations of low drag shapes for passenger vehicles were conducted in the 1930s but production cars of today have yet to approach the potential drag coefficients shown by that early research. Furthermore, the adoption of low drag styles has been resisted because of a perception of compromise to the exterior style and so recent aerodynamic developments have concentrated on changes to non-styled surfaces. However, environmental and ecological pressures are placing increasing demands on manufacturers to produce energy efficient vehicles and the contribution of aerodynamics in that equation is increasing, particularly with the adoption of technologies such as regenerative braking and measurements being made using more real-world use driving cycles. Relying on non-styled surfaces alone for drag reduction is unlikely to be sufficient to deliver the improvements required. In addition, and there is even some suggestion that passenger cars which are visibly streamlined have more appeal because owners can show their ecological credentials.

In this paper the authors discuss streamlined styles of the past and demonstrate that it is possible to re-evaluate these shapes using computer-based styling and CFD. Whilst recognising the importance of styling in sales, it is suggested that the integration of aerodynamics and styling will become essential for significantly lower drag forms to be presented in an aesthetically pleasing exterior design which also takes advantage of the potential changes in architecture offered by new propulsion technologies, materials, electronics and manufacturing technologies.

INTRODUCTION

For some years the world's automotive industry has been under pressure to develop vehicles which are less demanding on fossil fuels as the primary source of energy for propulsion and to be less harmful to the environment. In many western countries this pressure has been exerted in the form of direct legislation on tail-pipe emissions and in corporate taxation as well as indirectly through fuel excise duty which in turn has prompted consumer demands and expectations for more fuel-efficient vehicles.

Alternative fuels, such as hydrogen and bio-fuels and their associated technologies, have been the subject of research for many years but have yet to see widespread adoption. The availability and popularity of electric vehicles and hybrids has been increasing even though such vehicles are, at present, more expensive to purchase than equivalent petrol and diesel-fuelled vehicles. But alternative fuels are just one of several approaches to improving efficiency. Thus manufacturers are also renewing their interests in the use of lightweight materials and in the reduction of resistance to motion which arises from tyre rolling resistance, mechanical losses and aerodynamic drag.

When a vehicle stands in the showroom or is viewed on the road, all of the aforementioned energy-saving technologies, apart from one, are hidden from view. The exception is aerodynamics and while it is true that significant improvements in drag reduction have yielded from hidden features such as the smoothing of the underbody, it also remains true that once the exterior style is frozen then so too, essentially, are the inherent aerodynamic characteristics. Thus there is an intrinsic link between vehicle styling and aerodynamics. Yet a general review of the titles of technical papers published by SAE since 1960 on the subject of automotive aerodynamics and at the series of MIRA International Aerodynamics Conferences (biannually between 1996 and 2010) shows that comparatively few discuss the aerodynamic evolution of shapes and styles. The vast majority of papers discuss more generic details of flow mechanisms and the development of test facilities and techniques. They show that the understanding of automotive aerodynamics and the ability to conduct detailed tests and analyse any given design has progressed rapidly in the last 50 years and particularly in the last 20. What is not so extensively documented or apparent in the publications is how much influence the increased knowledge has played in the evolution of exterior styles.

Syndicated market research conducted into the “reasons for purchase” of passenger cars reveals that “exterior style” is always amongst the top three attributes in any market segment [1]. In most segments it remains the number-one reason for purchase and particularly so where competing products have similar levels of specifications and technical performance. This was recognised more than eighty years ago and was evidenced by the creation of styling departments within automobile manufactures, beginning in the late 1920s. When Alfred P. Sloan became President of General Motors, in 1923 he understood the value of style to increase sales. Harley Earl, who had been designing radically styled car bodies for Hollywood stars, was recruited to turn Sloan's ideas into a strategy. Earl set up the ‘Art and Color’ group at GM in 1927 and this became the first of what we now know as a Styling department. General Motors cars became sleeker (such as the Cadillac LaSalle of 1934, Figure 1), followed fashion of the day and were perceived as aerodynamic. This initiative changed the face of the market-place forever. The Buick “Y Job” of 1938 (Figure 2) was the first ever concept car [2]. Earl believed that in this way he could show the public what the future held for them. It was lower and longer than anything else around at the time. Sporting features such as a retractable hidden hood and headlights, it caused a sensation. This was a turning point and after this all the major automotive companies were forced to compete with GM on style.

Figure 1. 1934 Buick LaSalle

Figure 2. 1938 Buick Y Job (with Harley Earl in driver's seat)

With the exception of two distinct periods in automobile design during the 1920 to 30s and 1950s to early 1960s, it is probably true to say that the integration of aerodynamics and styling has been limited. Traditionally automotive aerodynamicists are people with an engineering-based background and their department is organisationally located within Body Engineering or a Whole Vehicle Engineering group. This positioning and generic timing plans for product development often results in aerodynamicists not contributing to vehicle shape development until late in the styling phase. Equally the role and techniques of Styling departments have evolved such that there is rarely a view that they have a ‘responsibility’ for delivering aerodynamic performance. Indeed, for many years the challenge for the vehicle aerodynamicist was: “make it aerodynamic but don't change the style”.

Changes in the present-day automotive industry and customer demands, however, provide a significant opportunity for true aerodynamic design. Firstly, environmental concerns and the price of energy have raised the cost-benefit of aerodynamic drag reduction and secondly, the new propulsion technologies present an opportunity for fundamental changes in vehicle architecture which could be exploited to help achieve significant drag savings. These opportunities must still be wrapped within an aesthetically pleasing body and so the key to future success in low drag vehicle design will be the close-working of the aerodynamicist with the designer (or stylist) at the very early stages of vehicle design.

However, none of the above considers the fundamental question of whether low-drag styles and aesthetics are complimentary or conflicting. In this paper we consider if this is possible by reference to the past, present and opportunities for future vehicle design.

THE CONTRIBUTION OF AERODYNAMICS TO VEHICLE ATTRIBUTES

Many readers will already be aware of the contributions aerodynamics makes to vehicle attributes. Hucho [3] summarises these as: Performance (fuel economy, emissions, maximum speed, acceleration), Stability (directional, cross-wind sensitivity), Cooling (engine, transmission, brakes, condenser), Comfort (ventilation, heating, air-conditioning, wind-noise) and Visibility (dirt, splash or spray, wiper lift-off). The link between exterior shape and the first two of these attributes may be relatively well appreciated but even within the industry there is less awareness of the opportunity for the stylist to help deliver, for example, low levels of wind noise or good cooling performance.

The effect of styling changes can be quantified for most of the above attributes through wind tunnel tests and/or computational fluid dynamics (CFD) analysis. In such tests the aerodynamicist should provide not only a status of the attribute but also an indication of the effect of a change in shape on that objective measurement. For some attributes it is also necessary or helpful to quantify a change in terms of benefit to the customer. For example, a reduction in a vehicle's aerodynamic drag coefficient (C_D) from 0.30 to 0.29 is obviously an improvement but how much benefit this might provide for a customer is not so well perceived. Maximum speed and acceleration times for this type of change can be quantified by experiment or through analytical predictions. For fuel-usage, however, the benefits resulting from aerodynamic improvements are less equivocal because they are calculated based upon various “drive-cycles” in which periods of acceleration, constant speed and braking are specified [4]. These drive-cycles originated from the legislation on vehicle emissions which began in the USA in the 1960s and were based upon mainly urban use. Whilst the cycles were appropriate to assist in combating urban pollution, it has long been argued that their low-speed bias undervalues the benefit of aerodynamic drag reduction and may not be truly reflective of real-world customer use. Indeed, some European manufacturers have additionally developed their own drive-cycles based on measurements of their customer's actual vehicle use. Schuetz [5] showed that the contribution to fuel consumption of aerodynamics in the New European Driving Cycle (NEDC) for a SUV class of vehicle amounted to 29% yet for typical Audi customer behaviour the contribution was more significant at 48%. Furthermore the adoption of technologies such as regenerative braking [6], hybrid power or range-extended electrically-powered vehicles potentially changes the relative contribution of aerodynamics to overall fuel consumption. Schrefl [7] showed that for the NEDC the ability to recover energy from regenerative braking could result in the proportion of fuel consumption due to aerodynamic drag increasing from 32% to 44% for a small passenger car. Thus it appears that the real-world importance of aerodynamics to customers may have been underestimated particularly in respect of fuel consumption, and that the relative significance of aerodynamic drag to energy consumption will increase as newer technologies are developed.

SEMANTICS

It is interesting to note that since the fuel crises of the 1970s, discussions in published literature mostly use the expressions “low drag” or “drag reduction”. Whilst technically correct, this also reflects the task of today's aerodynamicists within manufacturers to reduce the aerodynamic drag coefficient (C_D) of a given vehicle design. However, one could argue that the very terminology may be perceived as being “restrictive”, “dulling-down” or even “boring”. Some of this originates from the words used, particularly “drag”, which in this case means a resistance to motion or to slow something down and some may be linked with our recollections of low-drag concept cars for which the adage “form follows function” was often applied with little deference to aesthetics

In contrast, and yet with virtually the same aspirations of improving both performance and efficiency, the terminology used in the 1920s, 1930s and 1950s was arguably more positive and conveyed an image of excitement and technical progress. In these optimistic eras the terms “streamlining” and “streamlined” were more frequently used to describe the aerodynamic forms and which had been scientifically developed.

Thus it could be argued that a return to and more frequent use of the word “streamlining” today might help the acceptance of shape changes required to achieve aerodynamic efficiency and even avoid the common perception of aerodynamics being in conflict with vehicle styling.

The term, “streamlining” originated from fluid mechanics and is most commonly used when considering a visualisation of the flow around an object. When the flow is disturbed losses result and this usually indicates an increase in drag (or loss of lift) force. When the flow past an object is smooth and comparatively undisturbed losses are minimised. The trace of a fluid element within the flow is termed a “streamline” and these can be visualised either experimentally by means of seeding the flow (with dye-trace in water or smoke in air) or from pictorial outputs from CFD analysis. Thus the sight of an undisturbed, smooth streamline flowing past an object visually demonstrates efficiency and the term "streamlined" was coined to describe shapes of bodies which achieved this result. Although "streamlined" was originally applied to aircraft and then ground-transport vehicles, the association with efficiency per se has resulted in its use becoming more widely applied in design language to describe simplicity and pureness in form and also in business to describe processes which were stripped of complication and bureaucracy [8,9].

STREAMLINING IN THE 1920S AND 1930S

It appears that there has yet to be produced a definitive history of aerodynamic design as applied to road vehicles but readers who are interested in the topic and wish to see examples of overtly streamlined designs are recommended to include references [2,3,10,11,12] amongst their reading list. References to significant German language literature can be found in [3]. Furthermore, internet searches for streamlined vehicles will reveal many more pictures, descriptions and videos of streamlined concepts than appear in published literature.

The design language of the 1920s and 1930s is well documented [incl 10]. Rapid developments in aircraft and vehicle technology were inspired by the desire to travel further and faster and continued the pace of technological change which had been necessitated by the First World War. The streamlined forms which evolved from airship, aircraft, automobile and railway developments were copied and used for inspiration in the developing fields of domestic product design, architecture, graphic art, advertising and fashion, and were a significant influence in the era of "Art Deco".

The automobile had transformed within 25 years of its invention from basically an open "horseless" buggy to a fully enclosed vehicle expressing its own clearly defined design language. Aerodynamics considerations were a large part of this early design evolution and with these enclosed bodies, attention started to focus more on shape and form.

Whilst some of the streamlined vehicle styles of the 1930s were undoubtedly 'followers of fashion', the original leading developments, notably by Jaray [3,10], were the result of the same scientific approach to research and development as was evolving in the aircraft and airship industries. Much of the success of the Wright Brothers in achieving the first powered flight was due to their methodical and systematic approach to research and development, particularly with their wind tunnel experiments [13]. The use of wind tunnels became widely adopted as did the systematic approach to testing. Jaray's work for the Zeppelin airship company (Luftschiffbau Zeppelin) at Friedrichshaffen included the commissioning of the Zeppelin wind tunnel and his discoveries with airships were followed by investigations of aerodynamic forms for passenger cars [recounted in 14,15]. Amongst the early work by Jaray and his colleague Klemperer in 1922 were tests on simple body forms and how their proximity to the ground influenced their aerodynamic performance [3]. Their discovery of a "half-body" teardrop shape with wheels yielding a drag coefficient (C_D) just of 0.15 was less than 20% of typical automobiles of the period and remains a distant target for aerodynamicists of today. Figures 3 and 4 show the ideal streamlined shapes discovered during wind tunnel tests by Klemperer and Jaray in 1922.

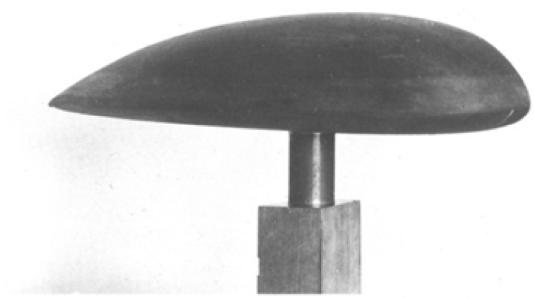

Figure 3. Idealised streamlined form for bodies close to the ground (after [10])

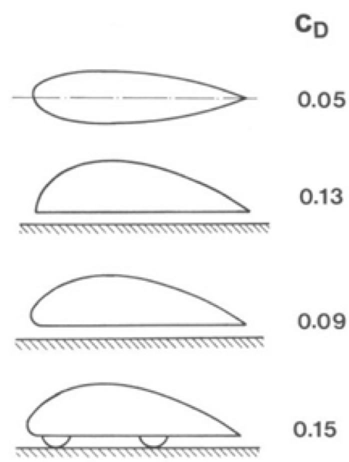

Figure 4. Klemperer and Jaray Test Results (after [3])

Although Jaray's work was not the first to attempt to reduce the aerodynamic resistance of road vehicles [3], it does seem to have been the most influential and is repeatedly quoted in published literature. Indeed, according to Hucho [3] the designation of the "streamlined car" appears to have been offered by Jaray in the title and contents of his paper "Der Stromlinienwagen, eine neue Form der Automobilkarosserie" of 1922.

Jaray produced designs directly for a number of companies and his work influenced that of a variety of manufacturers in Europe and North America. The sweeping, curved lines which Jaray employed were primarily functional but also gave cars an impression of dynamism and speed and were very much in keeping with the design language of the era. Ironically, whilst streamlining was being enthusiastically used at the time as a fashion statement for a variety of products (sleek was considered desirable) and in advertising with the aim of increasing sales, public acceptance of these first radically-shaped vehicles seems to have been resisted.

Figure 5. 1922 Ley by Jaray

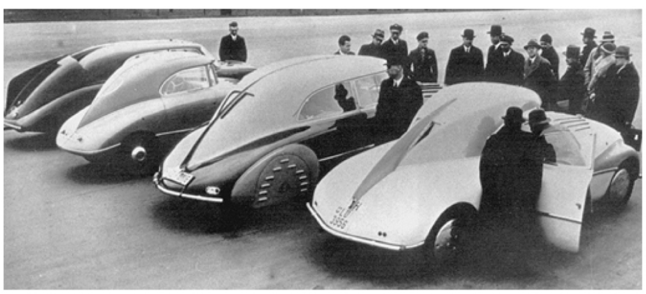

Figure 6. Jaray's designs for Tatra, Fiat Balilla, Maybach and Audi

The Chrysler Airflow is frequently quoted as an example of the hesitance in public acceptance of aerodynamic forms for automobiles, although this is disputed by Carl Breer. Breer [16] recounted that early wind tunnel tests began at Chrysler began in the late 1920s.

Their wind tunnel was built with the encouragement of Wilbur Wright and the discovery that when models of then current vehicles were reversed that they encountered 30% less wind resistance was reported to have been the origin of the design and development of the Airflow series. The Airflow was technically advanced in many features of its design including a monocoque body and advanced suspension for ride quality. The car was launched at the 1934 Motor Show in New York. Much of the publicity centred on the exterior style. A promotional film entitled “Trails of Triumph” [17] illustrated the new cars' aerodynamic performance through a 24 hour speed run - taking 72 new records at Bonneville - and an economy run across the USA from Los Angeles to New York. Initially the Airflow had been well-received but delays in early manufacturing undermined its reputation. Breer believed this was the primary cause of the poor sales rather than the new styling. It appears from [16] that given the early wind tunnel results, the body design of the car might have been even more radical as the engineering team favoured a tapered rear end to further reduce the drag which resulted in an unconventional seating arrangement of accommodating three people in the front and two in the rear. However, this feature was compromised by the insistence by the sales team that a car without a three-passenger seat in the rear would be a competitive disadvantage. So the sedan version became a 6-seater while the coupe retained the three-two arrangement allowing for more taper in plan and profile.

Figure 7. 1934 Chrysler Airflow Coupe

The Chrysler Airflow story above illustrates that streamlining of automobiles in the 1930s was employed for more than just the ability to travel faster. Reduced fuel consumption was just as much a selling point and was emphasised as one of the multiple benefits of the streamlined design. In 1933 Lay [18] published a paper entitled “Is 50 Miles Per Gallon Possible With Correct Streamlining?” in which he described a series of wind tunnel tests using small-scale models with interchangeable body section of varying geometries. The results provided Lay with a variety of drag characteristics with which to calculate fuel consumption. With correct gear-matching Lay suggested that the target of the paper was possible with streamlined designs of passenger cars. Again the body forms proposed were functional rather than aesthetic, a point which Lay made in his summary and highlighted may ultimately need to be compromised when applied to the needs of production vehicles. This regard to aesthetics was similarly emphasised by de Sakhnoffsky [19].

It is worth noting that there was, and to some extent has continued to be, a consumer resistance to the streamlined styles due to an association with problems with stability. In an era when cars were becoming faster, notable accidents, such as that of racing driver Bernd Rosemeyer in 1938 while attempting a speed record on a new German autobahn, gave rise to concerns over stability resulting from high lift forces, compared to the vehicle weight, which some streamlined forms generated. Whilst such extreme issues are rare for modern vehicles, and the aerodynamic development process takes high-speed and crosswind stability into account, the stigma and general wariness appears to have remained.

Jaray's concepts were based on pure streamlined forms which are still recognised as such today with the common perception of the "tear-drop" shape being optimum for aerodynamic efficiency (essentially for drag). Jaray's forms required a length to height ratio of 5:1 and a long tail to reduce the probability of separated flow regimes but such dimensions were impractical for passenger cars of that era and also subsequently. A scientifically derived development of this form, however, provided the practical solution for streamlining of automobiles. The discoveries of Lay, Koenig-Fachsenfeld and Kamm [3,10,11,18] showed that aerodynamic efficiency could still be achieved but with a truncated tail. Although Lay's 1933 publication pre-dates the publications of Koenig-Fachsenfeld (1936 - patent from work on model buses) and Kamm (1939), the aerodynamic opportunities of this form were mostly clearly presented by Koenig-Fachsenfeld and Kamm and the feature became known as the K-Back or Kamm-Back. For maximum effectiveness the truncated tail still requires aerodynamic shaping of the upstream form with boat-tailing. The truncation point is ideally located just ahead of the location at which flow would naturally separate. The vertical plane of the truncation (referred to as the base) has a cross-sectional-area which is smaller than the projected frontal area. The wake behind the vehicle is narrow and the negative pressure on the base is moderate due to the benefits of the upstream shaping and associated pressure recovery. Both these characteristics contribute to low drag and allow more practical length to height ratios of less than 3.5:1 to be capable of delivering low drag coefficients. The K-Back principle can also be beneficially applied to non-optimal upstream forms of both 3-box and 2-box designs so long as some degree of taper (with no flow separation) is employed ahead of the truncation. From a purely aesthetic point of view, the significance of the K-Back is that it gives the Designer more scope in style, distinctiveness and proportion without too great a compromise in aerodynamic efficiency.

Whilst photographs exist of many of the streamlined cars developed in Europe and North America during the 1930s comparatively little data is available detailing the development process of these vehicles. However, it becomes clear on reading period literature [including 2,3,14,16,18,20] that many of these designs were the result of experimental research by engineers. Models and full-size vehicles were tested in wind tunnels and road tests were conducted to examine flow regimes (including tufts fixed to vehicles and dust tests) and to evaluate maximum speed and fuel consumption performance. There is rarely a mention of a styling input to these designs and the streamlined forms appear to be the creation of engineers.

WERE THE CARS OF THE 1930S AS STREAMLINED AS THEY LOOKED?

In comparison to the conventional motor cars of the 1930s, the streamlined designs almost certainly provided an improvement in aerodynamic performance, particularly with regards to drag. Hucho [3], Ludwigsen [11] and Hoerner [21] have compiled drag coefficient data for some early vehicles but there appears to be little published data which gives a similar level of analysis to the broader range of aerodynamic characteristics, such as lift forces, side forces and yawing moments that would be considered today. Until recently this lack of data would limit the use of these early streamliners as a references, benchmarks or inspiration for future designs. If original vehicles or models are still in existence it is of course possible to wind tunnel test these or even 3D scan in order to create new models for testing. But access to such valuable properties, if they do exist, is rare and so the authors of this paper have used the capabilities of Styling and Computational Fluid Dynamics (CFD) software programs to demonstrate that it can be possible to reassess early designs.

The designs chosen for this study were the three-dimensional form of the Dymaxion Car designed by Richard Buckminster Fuller and the Streamlined car of Sir Charles Dennistoun Burney which comprised a mostly two-dimensional "tear-drop" profile. For both vehicles, the CAD geometry required for input into the CFD was created using Autodesk ALIAS 3D modelling software. Patent blueprints and photographs made it possible to model the Dymaxion car fairly accurately while the model of the Burney Streamliner was created based upon a few key dimensions and proportional judgements of published photographs and magazine drawings. In both cases the decision was taken to simplify some of the geometry for ease of design and speed of analysis. The assessment of the aerodynamic characteristics was facilitated by the use OpenFOAM (a trademark of OpenCFD Ltd). The models comprised 15 million cells and were run steady-state using the k-omega SST turbulence model. The mesh used was predominantly hex, with layers created by SnappyHexMesh. The models were run and forces monitored until a satisfactory level of convergence was achieved. All CFD runs were conducted using a wind test speed of 36.75 ms^{-1} (80 mph) and included the simulation of a moving ground plane and rotating wheels.

DYMAXION CAR

Richard Buckminster Fuller (1895 - 1983) was a designer, architect and engineer [2,22]. Despite no formal training in these subjects his interests were stimulated through experiences in boat-building, the food manufacturing industry, wartime service and working with his architect father-in-law. The death of his first daughter reportedly gave him the determination to help humanity by design and his resulting activities included designing, writing and lecturing. Fuller published more than 30 books and took out 28 patents. Amongst his more well-known works were the development (though not invention) of the geodesic dome and the Dymaxion House of 1929. Dymaxion was a brand name invented in 1928 for Fuller by Waldo Warren as combination of “dynamic”, “maximum” and “tension” or “ion” and was applied to several of his design concepts [23].

In 1932 Fuller began his designs of the Dymaxion Car. Plaster wind tunnel models, made by Isamu Noguchi, were a factor in determining its shape. The design comprised a three-wheel arrangement with two at the front and the one steering at the back. The engine was rear-mounted to maximise interior space and give the driver maximum visibility. Fuel economy was claimed to be 36 mpg (7.8l/100km) and Fuller claimed that with an example of Ford's first V8 engine fitted to have reached 128 mph (206kph). The car was 6m long and could accommodate 11 passengers. Three Dymaxion Cars were built in Starling Burgess's marine workshops in Bridgeport Connecticut with the first being introduced at the 1933 Century of Progress Exhibition in Chicago - Figure 8. Two further derivatives were built in 1934 [2,10,24] as shown in Figures 9 and 10. Applications for patents for the Dymaxion Car were made by Fuller in 1933 in the USA and Great Britain with the US patent being granted in 1937 [25].

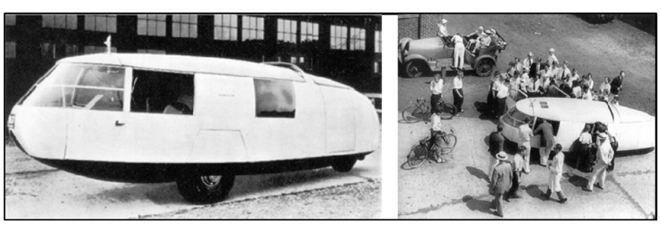

Figure 8. Dymaxion car No.1 - 1933

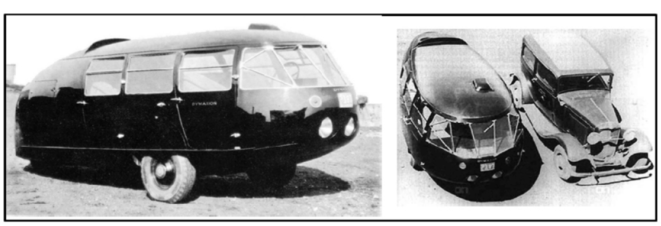

Figure 9. Dymaxion car No.2 - 1934

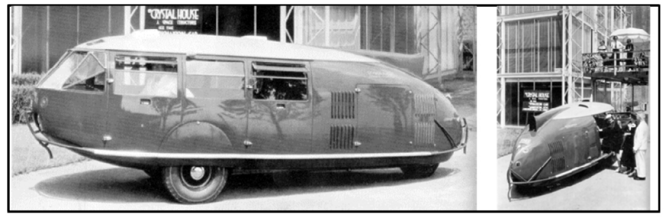

Figure 10. Dymaxion Car No.3 at 1934 Century of Progress Exhibition, Chicago

The Alias model and resulting CAD geometry for use in the CFD analysis are shown in Figures 11 and 12 respectively. The simplifications used for this example were: watertight body to include the sealing of the engine intake on the roof, simplified wheels and wheel arches and the elimination of suspension components and external details such as hinges, louvers etc. The front screen was modelled as per the rounded version of the Dymaxion Car No1 design and as shown in the patent drawings.

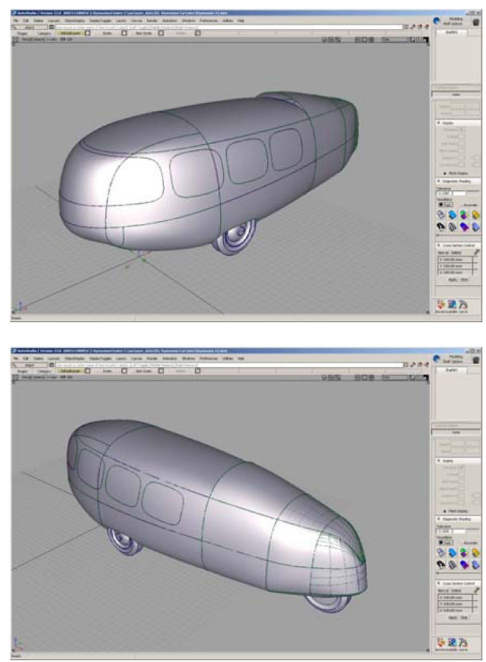

Figure 11. Autodesk Alias screen dumps of Dymaxion Car model

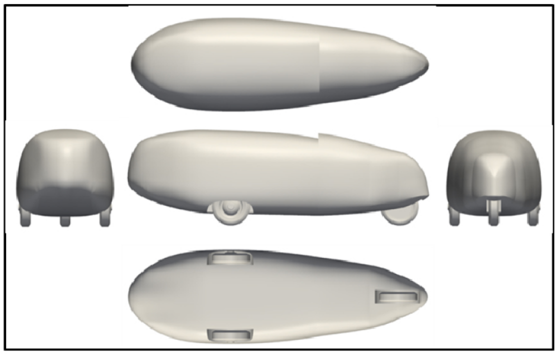

Figure 12. Dymaxion CFD CAD model

Table 1 shows the aerodynamic coefficient data produced from the CFD analysis. If we make allowances for the geometry simplifications and blanked engine intake (based on the lead author's personal experiences and historical experimental data), a more likely zero yaw drag coefficient is estimated to be C_D=0.24. Similarly adjusting the lift coefficients, estimates for lift at zero yaw are C_{LF}=0.10 and C_{LR}=−0.10. Thus the drag coefficient remains relatively low compared to current day production vehicles although the benefit is negated by a relatively large frontal area to give, with the above "corrections", C_DA = 0.68 m^2; although this is remains competitive compared to modern SUVs and people-carrier types of vehicles. Figures 13, 14 and 15 show that the primary sources of drag at zero yaw are the nose, the blanked engine intake and the exposed sections of the wheels and tyres. Interestingly, the drag of the nose is almost off-set by a zone of thrust (annulus of negative Cp-X shown in Figure 14 and numerically in the cumulative drag plot in Figure 16) from just behind the nose to the front wheels. The drag from the remainder of the body looks to be due to the wheels and some surface pressure influence on the sides and on the roof of the body aft of the front wheels. The nose-up pitching moment would be preferred for low ambient wind handling and this appears to be, from the pressure distribution plots in Figures 13 and 15 and the cumulative lift data of Figure 17, mainly due to positive lift acting on the underside of the nose and the acceleration of air over the forward area of the roof. On the underside of the body in the region of the front wheels there appears to be a beneficial area of negative lift (for handling) but with no significant drag penalty. The influence of the blanked air intake on the roof is clearly visible in the cumulative drag and lift data of Figures 16 and 17 but would be expected to be modified for the open condition.

Table 1. Dymaxion Car Aerodynamic Data from CFD Analysis

Dynaxion Car	Zero Degrees Yaw	15 Degrees Yaw
Projected Frontal Area	2.836m^2	
Drag Coefficient C_D	0.131	0.224
Drag Area C_D.A	0.372m^2	
Front Lift Coefficient C_{LF}	0.088	0.337
Rear Lift Coefficient C_{LR}	-0.141	-0.056
Yawing Moment Coefficient C_{MZ}		0.153

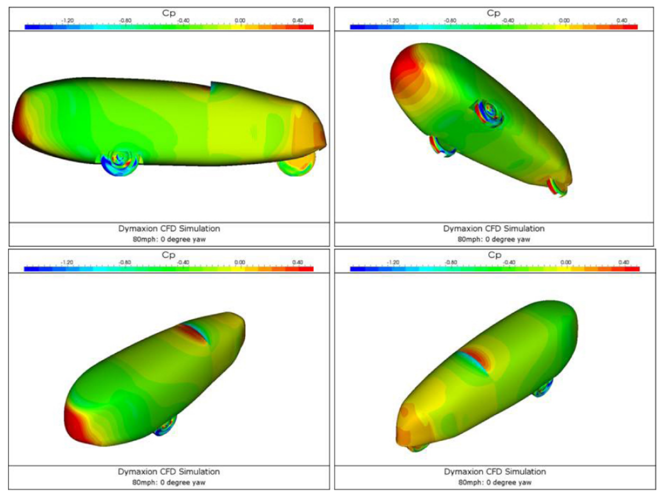

Figure 13. Static Pressure Distribution at Zero Yaw

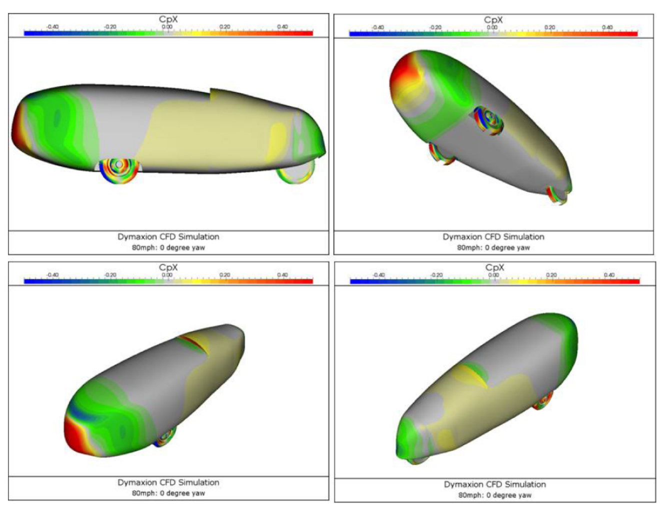

Figure 14. Pressure Coefficient in X-direction at Zero Yaw

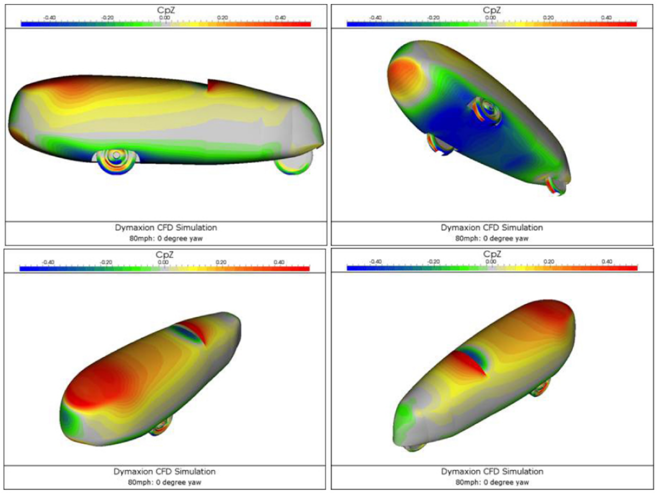

Figure 15. Pressure Coefficient in Z-direction at Zero Yaw

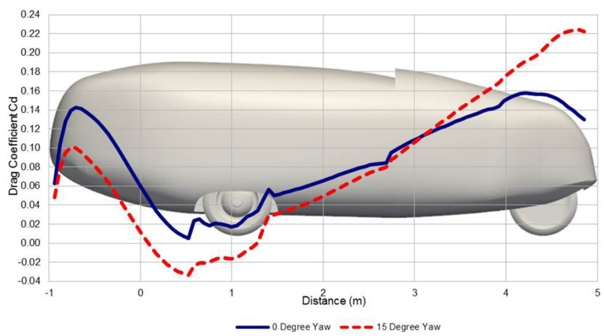

Figure 16. Cumulative Drag - Zero and 15° Yaw

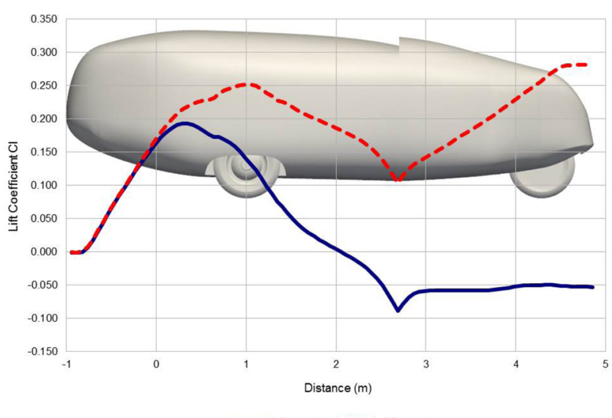

Figure 17. Cumulative Lift - Zero and 15° Yaw

Figure 18 shows "oil flow" patterns on the surface of the vehicle at zero yaw. The flow patterns look relatively undisturbed with the exception of around the wheels and roof intake, as would be expected and are commensurate with the low drag result give in Table 1. The vortices in the surface patterns shown in the rear view indicate the presence of unsteady flow which may also be partly attributable to the downstream influence of the roof intake. It would be interesting to learn if the revised design of the roof at the rear (with reward-facing exhaust outlet) suppressed this effect for the Dymaxion Car No. 3 (Figure 10).

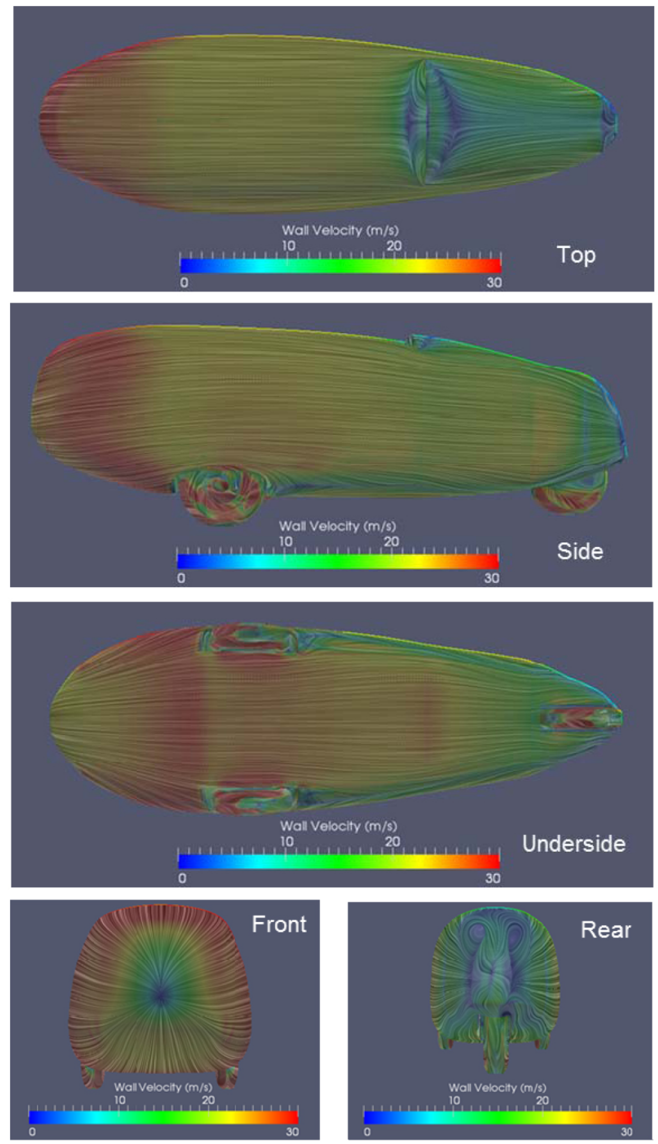

Figure 18. Surface Oil Flow Patterns - Zero Yaw

Figure 19 shows streamlines around the model at the centre-line for the zero yaw case. This result highlights an opportunity for further drag reduction with a modified rear end design for both the body and to influence the flow behind the rear wheel.

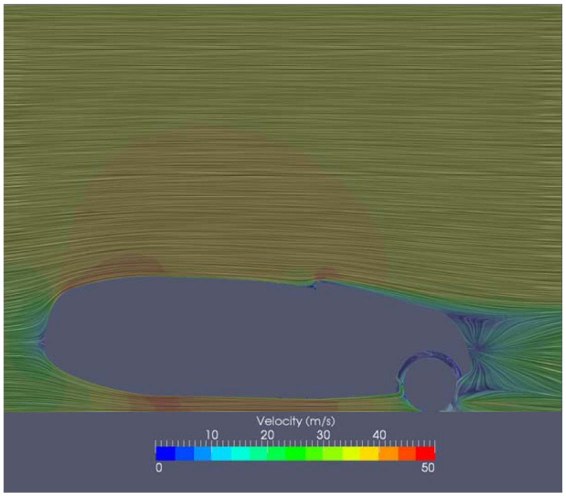

Figure 19. Streamlines at Y=0 (centre-line)

At 15° yaw, the aerodynamic characteristics are less than ideal with a high front lift and a yawing moment which is 32% higher than would be considered acceptable for a European passenger car of today.

BURNEY STREAMLINER

Sir Charles Dennistoun Burney (1888-1968) was an English aeronautical engineer and was the managing director of the Airship Guarantee Company, a subsidiary of the armaments firm Vickers-Armstrong, which built the R100 airship. His private interests led him to set up the company Streamline Cars Ltd to build technically advanced aerodynamic rear-engined cars. Starting in 1927, thirteen versions of the car were built to illustrate Burney's ideas and concepts. Compared to typical production cars of the day the streamlined bodywork was very long at just under 6m. The car's unusual aerodynamic design was eye-catching, with very little front overhang, but a long rear overhang (containing the engine). The underside was also covered in sheet metal to enhance aerodynamic efficiency. Burney's designs were more than just an aerodynamic body style. Significant thought was given to packaging and interior space in order to provide seating for seven. The spare wheel was carried inside one of the rear doors and the equivalent space in the opposite door was occupied either by a second spare wheel or by a cocktail cabinet [26,27,28].

Burney's paper published in SAE transactions in 1932 [29] gave details of the origins and reasoning behind the technical developments and packaging considerations of his Streamline car. Burney also gave some consideration to external styling although this took the form of potentially "refining" the completed designs to improve public acceptance rather than a compromise of technical performance in favour of pleasing aesthetics.

Streamlined Cars closed in 1936 although a licence was subsequently held by Crossley Motors to build the Streamlined Design. Some examples were built but volume production of the design was never undertaken. Figure 20 shows the Burney Streamlined Car.

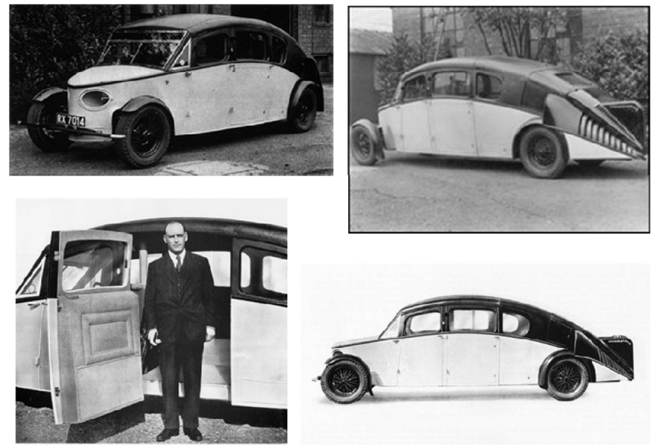

Figure 20. Burney Streamlined Car

The Alias model which was created to facilitate the CFD analysis of the Burney Streamline car is shown in Figure 21. As with the creation of the Dymaxion Alias model, some simplification was included for ease of construction and analysis. This included a watertight body, smooth underfloor, solid wheels and blanked intakes. Figure 22 shows the associated CFD model.

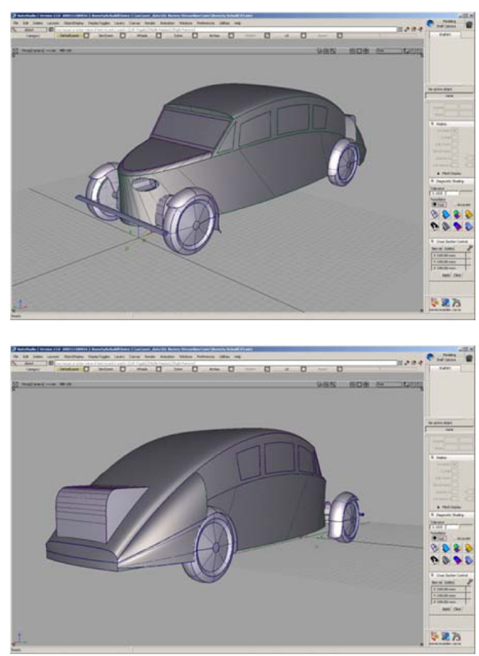

Figure 21. Autodesk Alias screen dumps of Burney Streamlined Car model

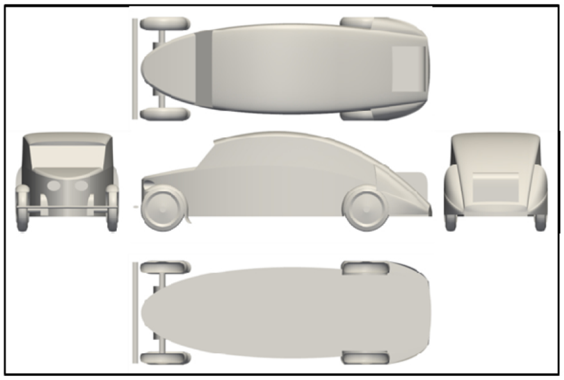

Figure 22. Burney Car CFD CAD model

Table 2 summarises the aerodynamic characteristics of the Burney streamlined car resulting from the CFD analysis. As with the Dymaxion car, the simplifications of the model will have led to some inaccuracies of the analysis compared to the cars as built, but they are a reasonable indication of the basic performance.

Table 2. Burney Streamline Car Aerodynamic Data from CFD Analysis

Burney Streamliner	Zero Degrees Yaw	15 Degrees Yaw
Projected Frontal Area	3.144m^2	
Drag Coefficient C_D	0.466	0.578
Drag Area C_D.A	1.465m^2	
Front Lift Coefficient C_{LF}	0.266	0.247
Rear Lift Coefficient C_{LR}	0.183	0.207
Yawing Moment Coefficient C_{MZ}		-0.197

The zero yaw drag coefficient of 0.466 is an underestimate of the actual car because the rear engine air intakes were blanked. However, even allowing for large cooling drag of 0.03, the car still achieved a drag coefficient of approximately 50% of that typical in its era. Figures 23, 24, 25, 26, 27 show that the nose, screen and front wheels provide approximately 60% of the contribution to the drag whilst the profile of the roof initially offsets the penalty of the screen (before the position of maximum height) after which the induced drag and effect of the blanked intakes and exposed rear wheels contribute to the remaining 40%. The initial shape of the roof and front planform curvature both offer aerodynamic advantages in terms of drag. The engine cover at the rear, which protrudes from the rear bodywork offers some advantage in breaking the lift and associated drag, but is partly compromised by its rounded trailing edge. The axle lift performance is undesirably high compared to current-day vehicles but not entirely unexpected from the amount of roof curvature. However, the step between the roof leading edge and screen provides a disproportional effect. The mudguards contribute to lift on the upper portion and drag through separated flow from the rearward facing surfaces.

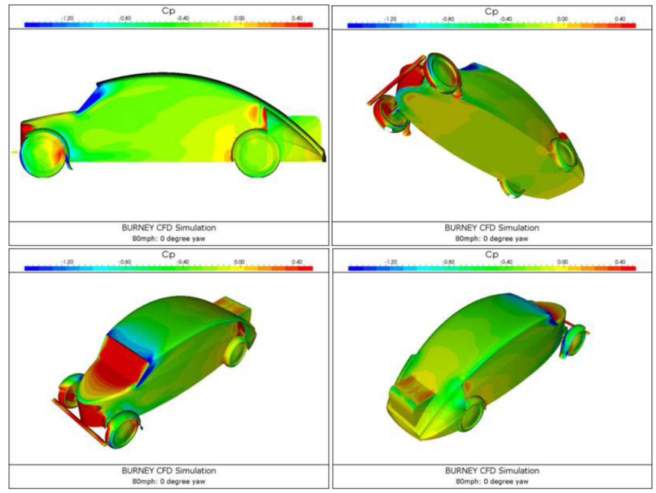

Figure 23. Static Pressure Distribution at Zero Yaw

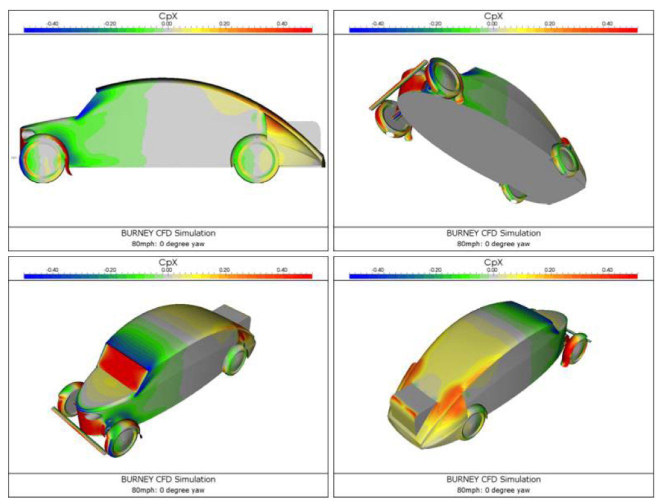

Figure 24. Pressure Coefficient in X-direction at Zero Yaw

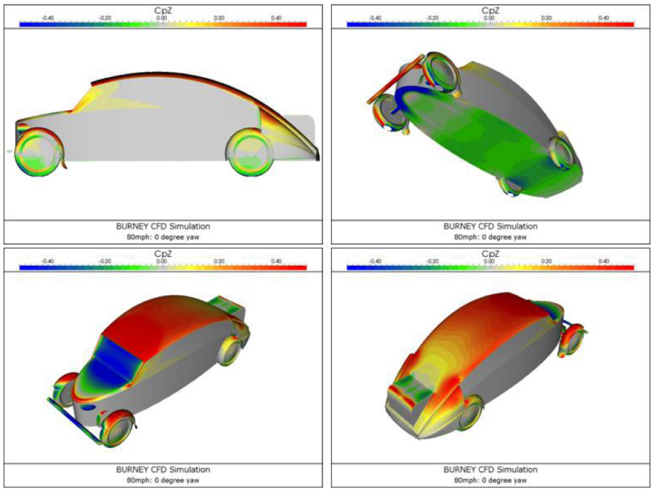

Figure 25. Pressure Coefficient in Z-direction at Zero Yaw

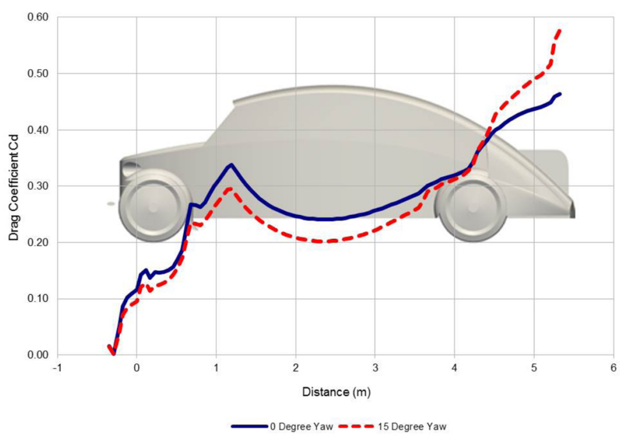

Figure 26. Cumulative Drag - Zero & 15° Yaw

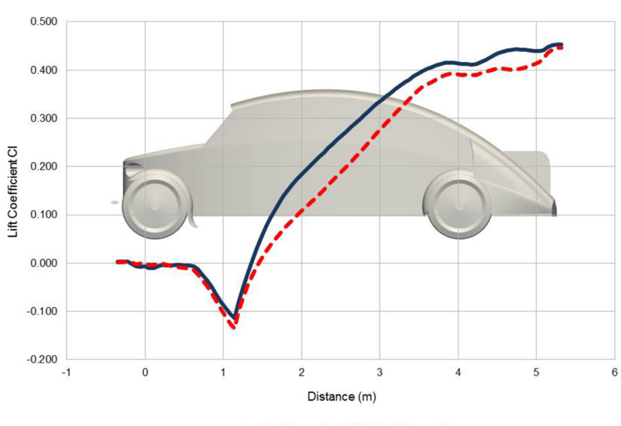

Figure 27. Cumulative Lift - Zero & 15° Yaw

Figure 28 shows the surface oil flow patterns on the Burney Streamliner. The exposed wheels cause unwanted disturbances along the side and particularly towards the rear where the influence of the mudguard causes a local upwash. The fully smooth floor gives a relatively good flow pattern with the exception of a separation at the leading edge of the nose and a drawing of flow underneath the car rolling along the side edges. These are caused by the sharp edges of the joint between the floor and main body.

The step at the top of the screen provides a significant separation on the leading edge of the roof. If the roof and front screen joining edges were flush this might have reduced this result but the flat nature of the screen and screen angle would not have been sufficient to eliminate this problem entirely. The separation has also has a significant effect on the flow over the entire length of the roof and whilst undesirable in itself may have reduced the potential magnitude of the lift acting on this surface.

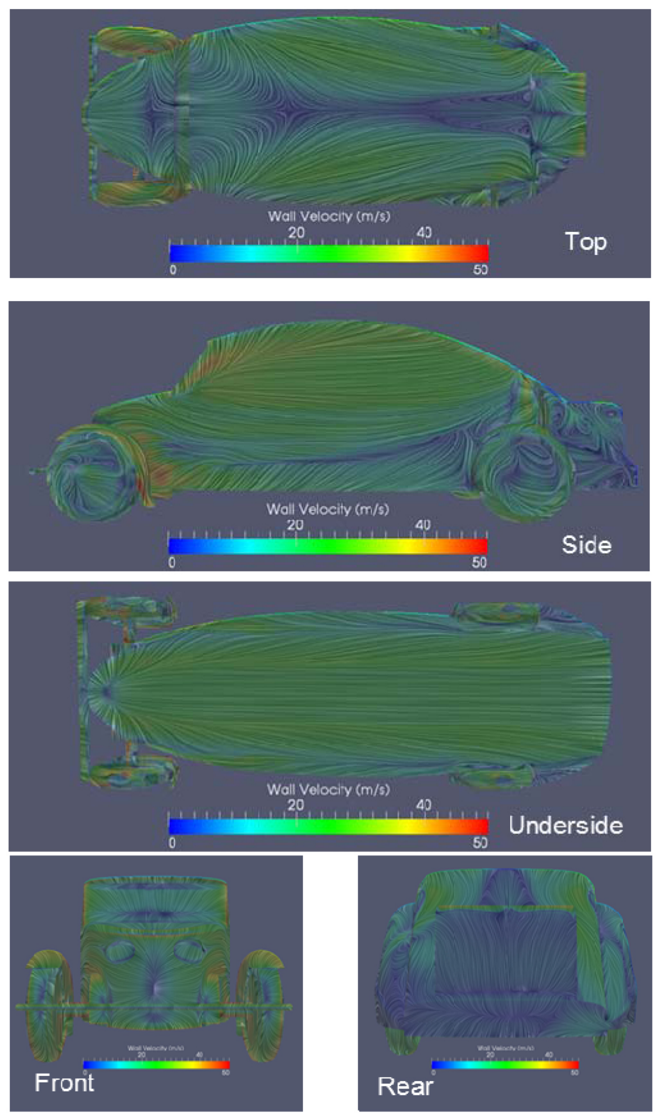

Figure 28. Surface Oil Flow Patterns - Zero Yaw

The key effects shown in the plot of streamlines at the centreline (Figure 29) are the separations at the roof leading edge and along the backlight, the downwash at the rear caused by the generous radius on the engine cover trailing edge and the separation on the leading edge of the floor at the nose.

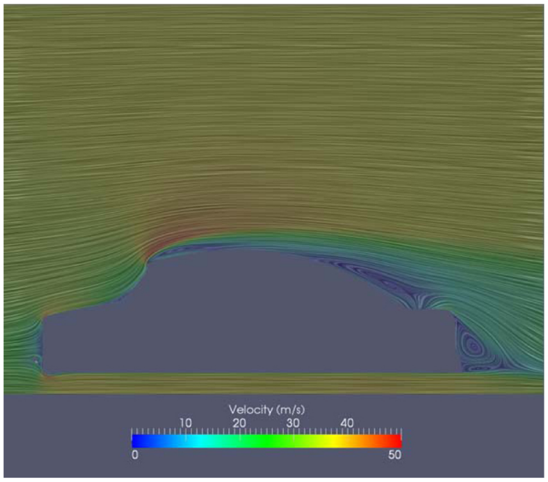

Figure 29. Streamlines at Y=0(centre-line)

Interestingly, the large side-area of the Burney Streamliner appears to have resulted in a negative yawing moment at 15 degrees of yawing implying a self-correcting effect under crosswinds.

The CFD analyses of both the 1930s designs showed that modern technologies can be very useful in providing the opportunity to assess vehicles for which little aerodynamic data exists and to generate not only force and moment data but also examine the flow and pressure regimes in order to deduce the areas of efficiency or source of problems. Whilst both show opportunities for further aerodynamic development, they also show a significant reduction in drag coefficient compared to the volume production cars of their era. The Dymaxion car looks close to a drag optimum style and serves as a useful reference for low drag forms. Readers, may notice as did the authors, a remarkable similarity in shape to a humpback whale and whilst not noted as an inspiration for Buckminster Fuller's design, water borne creatures have been the inspiration for some low drag aerodynamic concept vehicles. The mostly two-dimensional form of the Burney Streamlined car gives it some issues with lift and induced drag which are not unexpected for such a profile and demonstrating that in practice even some pure aerodynamic forms can result in undesirable characteristics.

For comparison, the drag coefficients of some other notable vehicles of the era are given in Table 3.

Table 3. Drag Coefficients of Early Streamlined Vehicles

Vehicle	Drag Coefficient C_D	Year	Reference
Rumpler Tropfenwagon	0.27	1921	[3]
Tatra T77	0.21	1935	
Chrysler Airflow Sedan	0.56	1936	[30]
Lincoln Zephyr	0.45	1936	[31]
Alfa Romeo 8C 2900 B	0.42	1938	[32]

STREAMLINING IN THE 1940S, 1950S AND EARLY 1960S

The initial resistance to streamlined passenger car designs was short-lived and by the late 1930s and early 1940s more European and North American manufacturers were introducing models which shared many of the key characteristics of the streamlined designs, i.e.: curvaceous bodies, sloped windscreens, wheel-housings within the main body, enclosed lamps and tapered tails. For example, the 1936 Lincoln Zephyr (Figure 30) was outwardly similar in profile to the Chrysler Airflow but its later introduction allowed it to be both accepted by the public and popular. The same basic design trends were to be found on many production cars during the 1940s and 1950s.

Figure 30. 1936 Lincoln Zephyr

Aerodynamic development of motor cars continued after the Second World War. In North America, production car design once again took inspiration from the aircraft industry and particularly from the rapid post-war military jet aircraft designs together with the emerging spacecraft technologies. By the late 1950s models such as the Crown Imperial (from Chrysler) and Cadillac Eldorado, Figures 31 and 32, had evolved to become more angular and had sprouted exaggerated tail fins. Whilst the fins had some aerodynamic contribution under crosswind conditions, it is unknown as to how much aerodynamic development was afforded to other external features of cars of this type.

Figure 31. 1957 Crown Imperial

Figure 32. 1959 Cadillac Eldorado

The link between aerodynamics and styling was not lost in this period as evidenced by the 1957 description by Exner of the work undertaken at Chrysler on the DART experimental car [33]. The car retained a curvaceous body but in longer and more slender proportions than those of the 1930s and the tail fins were a result of aerodynamic development, as shown in Figure 33.

Figure 33. Chrysler Dart

In Europe the smaller proportions of vehicles meant that angular bodies were less readily adopted for volume production cars and where tail fins were included they were much smaller. European aerodynamic concept cars such as the Alfa Romeo BAT (Berlinetta Aerodinamica Tecnica) series retained the curvaceous body styles which extended to include the tail fins.

Alfa Romeo commissioned design house Bertone to build the three BAT concept vehicles, shown in Figure 34, based on extensive research on the effects of drag on a vehicle. All three cars were built on Alfa Romeo 1900 chassis. The first car, BAT 5 was revealed at the 1953 Turin auto show with a reported drag coefficient of C_D=0.23. BAT 7 and BAT 9 were revealed at the Turin Auto Shows in 1954 and 1955 respectively. BAT 7 was the ultimate aerodynamic development in the series with a drag coefficient of C_D=0.19 whilst BAT 9 demonstrated an evolution which was considered to be closer to a production sports car.

Figure 34. Alfa Romeo BAT cars (L to R BAT 5, BAT 7, BAT 9 in both pictures)

AERODYNAMIC DEVELOPMENT SINCE THE 1960S

Since the early 1960s the aerodynamic development of road cars has mostly comprised small changes to the style. This technique of the optimisation of body details, as described by Hucho et al in 1976 [35,36], has become the standard approach to the development of series production cars by the aerodynamics departments of most automotive OEMs worldwide. The process involves systematic changes in shape with results plotted against geometrical modifications. Changes are made until an aerodynamic optimum form is identified. Hucho [37] provided a table to indicate the likely trends of changes in drag with geometry which would be obtained from systematic investigations for different regions of passenger cars. The systematic approach has been used by many authors and their results provide a useful database for the trends in response of aerodynamic characteristics to changes in geometry for both the aerodynamicist and designer (stylists). The use of simplified reference car models in such work by authors including Ahmed [38], Glihaus and Renn [39], Carr [40,41,42] and Howell [43] has provided generic data which has long-term value rather than being vehicle specific.

The systematic approach to shape development has also been shown to deliver very good aerodynamic characteristics as illustrated for the 1983 Audi 100 by Buchheim etc al [44] and for the 1989 Opel Calibra by Emmelmann et al [45]. Both cars claimed the lowest drag coefficient for production cars at their launch with the Audi 100 having C_D=0.30 and the Opel Calibra having C_D=0.26. Indeed, the low aerodynamic drag coefficient of the Audi 100 was the principle marketing statement in the UK at launch and was the first car to use aerodynamics as differentiator in this way. The early cars also included the badging "C_D=0.30" in the rear quarter-light as featured in the television commercial at launch [46].

Comparatively rarely is the opportunity presented, even with concept cars, as it was in the 1930s to work from basic principles of pure aerodynamic forms. One notable exception to this, however, was the Pininfarina - CNR car of 1976 [47,48] which achieved a drag coefficient of C_D=0.20 as a full-scale prototype.

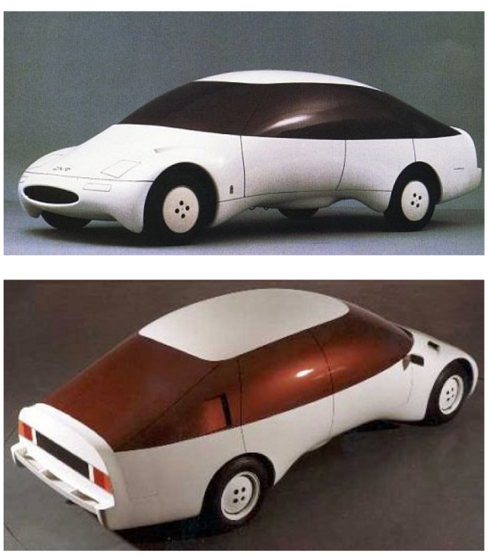

Figure 35. Pininfarina - CNR Car 1976/77

Whilst aerodynamicists have continually strived to improve aerodynamic efficiency since the 1960s, the demand for major reductions in aerodynamic drag and lift has been limited. This is partly because the real cost of fuel was low and that performance and handling was limited by low-powered engines and narrow tyres. The response to the fuel crises of the 1970s, however, and the ecological concerns since the start of the 21st century have been the two major global concerns which have raised the priority of aerodynamics within manufacturer development programmes and have led to investments in new or upgraded wind tunnels and more extensive CFD capabilities. In general, however, the reduction of aerodynamic drag for passenger cars has been gradual as shown by Hucho [3] and MIRA [49] and illustrated in Figure 36 as composite data from published and un-published sources. The stepped nature of the curve mimics the advances in test technology and the legislative demands for economy and reduced emissions.

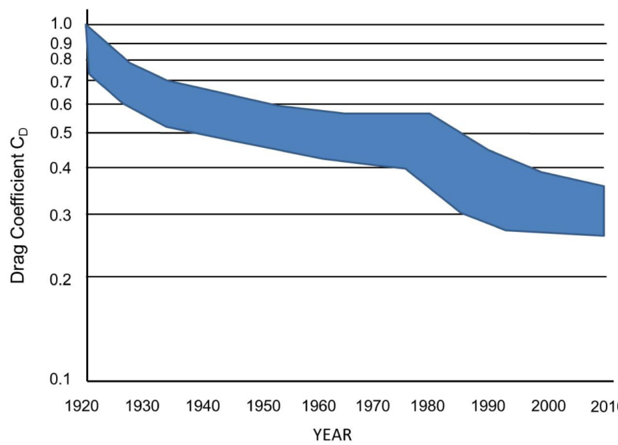

Figure 36. Trend in Passenger Car Drag Reduction

Today the lowest quoted drag coefficients of passenger cars is C_D=0.24 and the proportion of vehicles on sale with coefficients of less than 0.30 is increasing. However, amongst small cars of conventional design sub 0.30 drag coefficients appear difficult to achieve. C_D=0.32 is amongst the best of current vehicles and significantly higher than the A-class Audi A2 of 1999-2005 which achieved C_D=0.26 to 0.29 depending on derivative. Notably this car could be considered to be a mostly two-dimensional streamlined form with the low drag being apparently due to the highly curved rood, controlled separation and minimised drag from the cooling system, tyres and underfloor.

Figure 37. Audi A2

Whilst there have been some significant reductions in drag coefficients this benefit has been offset, and in some cases negated, by the increase in size of passenger cars. In most production car classes, the projected frontal area has increased in the last 20 years by between 5 and 10% in order to accommodate structures to meet crash and pedestrian impact legislation, desires for greater comfort and functionality and to accommodate anthropometric changes. Interestingly, the original Mini had a frontal area of $1.48m^2$ while the eventual successor BMW Mini (R50) has a frontal area of $1.98m^2$ - 34% bigger. Thus in order for successive generations of models to offer less drag force at any given speed, the task for aerodynamicists has been to more than match the increase in frontal area with a reduction in drag coefficient. As an example, BMW's development of the E90 derivative of the 3-series showed that this was possible [50] and how targets were set to ensure each generation of the 3 series to that point was an aerodynamic improvement on the previous version. Thus the important issue to draw from this observation is that the design of aerodynamically efficient cars is not just about shapes with low drag coefficients, but also a consideration of size.

AERODYNAMICS AND DESIGN (STYLING) - FUTURE OPPORTUNITIES

If we accept that aerodynamics must continue to play an important role in the reduction of energy consumption and harmful emissions, then the question arises of what it will take to achieve further reductions in drag? Since up to 75% of the aerodynamic drag can still be attributed to or be influenced by styled surfaces [43], the exterior design would continue to appear to offer a significant opportunity. Yet from the discussion above, history shows that pure aerodynamic forms still meet some resistance from customers due to aesthetics.

Ironically, many of the shape requirements to achieve low drag are already incorporated in today's passenger cars. Features such as roof curvature, boat-tailing, tyre coverage, optimum trunk lid positioning, features to control separation and low drag door mirrors are incorporated into C and D-class vehicles such as the BMW E90 (Figure 38) and Mercedes E-Class coupe (Figure 39) which achieve C_D=0.26 and 0.24 respectively. So it would seem that it is possible to achieve comparatively low drag yet retain the appearance of a conventional passenger car. Indeed, it could even be argued that it has been possible to 'disguise' these forms with clever use of feature lines, glazing, exterior trim and proportioning. In this way aerodynamic requirements could be incorporated at the beginning of the design process with the aid of styling. For some manufacturers it is also true that their corporate visual identity and styling cues lends to a more favourable aerodynamic form.

Figure 38. BMW 3 Series Sedan E90

Figure 39. Mercedes E-class Coupe

A consideration for both the Aerodynamicist and the Designer is that future vehicle technology may also contribute to the achievement of reduced aerodynamic drag. The increasing effort of manufacturers to introduce full electric and range-extended electric vehicles offers the first major opportunity for a change in vehicle packaging of volume passenger since the early days of the motor car. The potential to package compact electric motors and batteries around the car moves the architecture away from the conventional front-engine installation. Furthermore, the size of range-extender power-units appears to offer the opportunity to consider rear-mounted installations which can offer some advantages in managing exhaust and cooling outlets and reducing the requirements for front cooling intake apertures (which are a source of significant drag for conventional vehicles). If the size and weight of the range-extenders can be further reduced then the concerns of stability and crosswind response (which can be degraded by rear-mounted power units) may be avoided. An additional by-product of the new architecture opportunities might also be that by packaging components in new locations, future crash performance requirements can be more easily met without having to increase the projected frontal area of the vehicle. Occupant and luggage packaging could also be reviewed as aerodynamic forms may offer new opportunities to maximise accommodation. The streamlined designs of the 1930s have shown the possibility for improved occupant design and features such as the Chrysler Airflow 3+2 seating arrangement may become more acceptable to facilitate more streamlined upper body designs. Other developments in vehicle manufacturing technology such as the use of composites, high-strength steels, rapid manufacturing techniques and alternative tooling strategies can all aid the adoption streamlined design for all components and assemblies subjected to aerodynamic loading as is 'de rigueur' in motorsport. Such technologies combined with electronic controls may also offer the opportunity for active surfaces to extend beyond the current application to intake blinds and spoilers so as to allow static aesthetics and dynamic functionality to be more easily combined in physical morphing with speed.

Figure 40 (after Hucho[3]) illustrates the two strategies which have been used for aerodynamic shape development. As discussed previously the 'optimisation' of a given style has been the traditional approach since the 1960s and has resulted in some substantial reductions in drag. However, and by reference to passenger car drag time-lines such as Figure 36, it can be argued that this technique might now look to be providing diminishing returns and that a return to the radical approach of the 1930s may be required for worthwhile gains to be achieved. In this alternative process the starting points are scientifically created low-drag aerodynamic forms which are then developed into new generations of passenger vehicles. Fundamentally there is no evidence to suggest that aerodynamic forms are not intrinsically acceptable from an aesthetic point of view, but it would appear to be true then when in proximity to the ground and with wheels added there is the potential for a streamlined form that is wrapped around an existing passenger car package to appear 'heavy' or be proportionally unbalanced. So if starting from streamlined forms is to become a strategy once again then the role of the designer to aid the aerodynamicist is crucial.

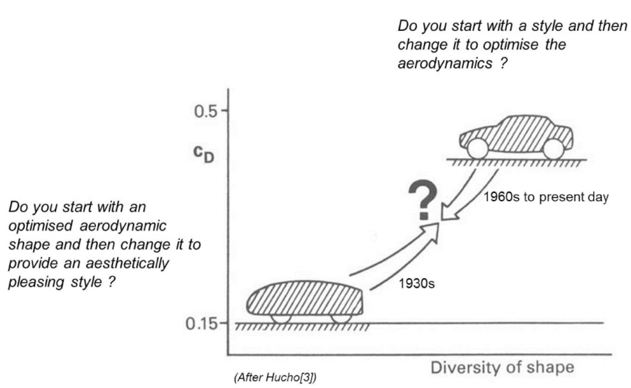

Figure 40. Shape Development Strategies based on Hucho [3]

Perhaps fortuitously there has also been a re-emergence within the last decade of customer associations of shape with efficiency. This might be more by accident than by design, but amongst the early vehicles to be available for sale with hybrid technology were cars with a more overtly streamlined body design, particularly in side profile. Whilst the aerodynamic shape was a key part in the overall vehicle concept, the rise in ecological awareness and increase in fuel costs has meant that these vehicles have become desirable principally for their alternative powertrain technology. Their adoption by celebrities wishing to be seen to be ecologically aware seems to have contributed to their popularity as has their favourable tax positioning. The valuable point here for the aerodynamicist is that streamlined styles are becoming the visible evidence or a 'signature' of efficiency and hence not only acceptable but even desirable. There is the possibility that the distance of these streamlined body-forms from conventional vehicle styling now proves to be a marketing advantage - in contrast to the resistance of aerodynamic forms of the past.

This perception of efficient and ecologically desirable styles for passenger cars may have also been assisted by developments in commercial vehicle design, particularly in the UK where the adoption of trailer units with highly curved roofs by one major retailer has been accompanied by the logo "Streamlined to Save Fuel" emblazoned in large type on the side-walls of the trailer. It could even be suggested that the particular retailer is advertising its ecological strategy through the form of its trucks. In many respects this physical use of a radical, highly visible and eye-catching streamlined vehicle design as an advertisement is similar to that used by Beer manufacturers in North America in the 1930s [19,51,52], although ecology was not the motivator in this case.

Throughout this paper we have indirectly implied that key to the successful development of future streamlined or low drag designs will be the interaction of the Designer (Stylist) and the Aerodynamicist. If there is a marketing advantage in aerodynamic forms as a visual cue to ecological sympathy then the Designer will require the assistance of the Aerodynamicist to provide forms which not only appear functional but also deliver real-world benefits in efficiency. Equally, and as previously mentioned, pure aerodynamic forms applied to passenger vehicles may still not be as aesthetically acceptable as might be envisaged and so the Aerodynamicist will require the assistance of the Designer to add features which make these shapes more desirable. In order to facilitate and heighten this interaction the authors suggest that there is likely to be a need for a change in traditional organisational structure within automotive manufacturers in which the Styling and Aerodynamics departments would become fully integrated. The compatibility of Styling and Aerodynamics departments is actually more obvious than some might think with modelmaking skills, technologies and materials together with manufacturing requirements already being common for both departments to support their shape development processes in the Studio and in the Wind Tunnel. The timing of aerodynamics development needs to be common with styling activity if the benefits of both functions are to be jointly maximized and some manufacturers already have their wind tunnels located in close proximity to their Styling studios to aid development. The common use of CAD data can also facilitate early application of CFD techniques which already offer the opportunity for increasingly detailed pictorial and illustrative aerodynamic data and to be fed back to the Designers and increasingly CFD-morphing technology is being developed for use by both Aerodynamicists and Designers [53]. Despite these existing commonalities there are perhaps two elements which are lacking in order for such integration to be widely adopted. The first is a lack of opportunity for the appreciation of each other's skills in higher education and training. More correctly, the fulfillment of this is rather one-sided at present because whilst there is incorporation of aerodynamics as a taught subject within some vehicle design courses [53,54,55], aerodynamicists rarely receive any design or styling appreciation training. Yet there is much merit in aerodynamicists having some intuitive feel for shape and form to support their test work and to marry this to an appreciation of flow structures. The second element which seems to be lacking is a more general appreciation within senior engineering management as to the closeness and interaction of the tasks and timing of the work of the Designer and Aerodynamicist thereby often resisting an organisational structure which places the two departments in the same functional or operating group let alone together in the Styling Studio and in the same place on generic timing plans.

CONCLUSIONS

In this paper we have attempted to offer both Aerodynamicists and Designers an opportunity to appreciate the significant efforts which have been made in the past to offer streamlined (low drag) aerodynamic forms for passenger cars and to provide a useful foundation of references for further reading and research.

The 1920s and 1930s were shown to be the most radical era in the history of the motor car to date in attempting to adopt streamlined styles. However, published data is comparatively rare and so the authors have demonstrated, by considering two 1930s designs, how modern styling and CFD analysis software can be used together to provide a more detailed understanding of their aerodynamic characteristics.

Whilst a reduction in passenger car aerodynamic drag has been achieved, the progress was limited initially by a public resistance to pure aerodynamic forms interpreted as automobile body styles and then potentially as a result of the aerodynamic optimisation process in which small changes were made to a given style based on the fashions of the day. Traditionally there has been a division between what the design department feels is right for the market and what aerodynamicists know is right for the efficiency and stability of the vehicle. But there is now a trend where the old demarcation lines are gradually being reduced. For the future the authors have suggested that the integration of the styling and aerodynamics departments offers advantages in operations and functional achievements and that revisions to education and training would be beneficial.

The authors also suggest that overtly aerodynamic body styles may become desirable for their own sake as a means of illustrating ecological awareness. Since the new powertrain technologies will be hidden from view, a streamlined exterior style would provide a perceived ‘distance’ from conventional vehicles as well as a functional contributor to efficiency.

There is likely to be an increasingly significant role for the Designer to offer in helping to provide aesthetically pleasing aerodynamic forms or indeed incorporating aerodynamically preferred surfaces within a given style. If there is a sufficient knowledge base where Designers, Aerodynamicists and Packaging Engineers work together from the initial concept stage, then there is a very high degree of probability that an aesthetically pleasing aero efficient design can be achieved and that new materials and manufacturing technologies may provide for an even greater range of styling solutions.

Finally, the authors would like to quote from the conclusions drawn by Professor Lay in his 1933 SAE paper. Optimistically we would offer that the opportunity to fulfill the sentiments of his last sentence may now be provided by the changes in vehicle design and technology required to meet the 21st century desires for zero emissions. Plus ça change.

Lay [18]:

“Suggestions Offered to Car Builders

1. Remove all barnacles or wind-claws from the car. If they cannot be removed, build the body out to enclose them.

2. Replace all sharp edges and radii and corners with round edges and corners of generous radii.

3. Build the front of the vehicle to bore a hole through the air with the least possible disturbance of the surrounding air.

4. Build the rear of the body to lay the air back in place without eddies or turbulence.

5. The shape for the ideal streamline form naturally provides space for the housing of the engine at the rear.

6. The public is becoming streamline conscious and will welcome these changes at a more rapid rate than ever before.

At this time it is particularly keen to accept changes which reduce operating costs.

7. We must push our attack on the problem of the variable speed automatic or semi-automatic transmission. The advantages offered by such a device are both numerous and important.

The difficulty in applying these suggestions is fully appreciated. It is certain that the public will spend far more money for its conception of beauty in a car even when it has less activity and a lower fuel mileage than it will for a streamlined monstrosity. But the beautiful car of a decade ago appears uncouth today. Moreover, the form of the streamlined car naturally offers greater opportunity to the artist who has the vision to appreciate it. A little engineering, a little art and some education of the public may accomplish much.

The dove is streamlined by nature, so that it can fly with the least possible air resistance, and we call it beautiful. The day is coming when we shall drive streamlined cars and marvel at their beauty."

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CONTACT INFORMATION

Dr. Geoff Le Good
Managing Director - G L Aerodynamics
Part-time Lecturer Coventry University School of Art and Design
geoff.legood@gl-aerodynamics.co.uk
geoff.legood@coventry.ac.uk

Chris Johnson
Director of Design Project Work
Coventry University School of Art and Design
chris.johnson@coventry.ac.uk

Brian Clough
Senior Lecturer in Automotive Design
Coventry University School of Art and Design
b.clough@coventry.ac.uk

Dr. Rob Lewis
Managing Director
TotalSim Limited
rob@totalsim.co.uk

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